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ECONOMIC ASSESSMENT OF BIOECONOMY IN AGRO-INDUSTRIAL COMPLEX OF THE REPUBLIC OF KAZAKHSTAN: WORLD EXPERIENCE AND PRIORITY AREAS

ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ АӨК-ДЕГІ БИОЭКОНОМИКАНЫ ЭКОНОМИКАЛЫҚ БАҒАЛАУ: ӘЛЕМДІК ТӘЖІРИБЕ ЖӘНЕ БАСЫМ БАҒЫТТАР

ЭКОНОМИЧЕСКАЯ ОЦЕНКА БИОЭКОНОМИКИ В АПК РЕСПУБЛИКИ КАЗАХСТАН: МИРОВОЙ ОПЫТ И ПРИОРИТЕТНЫЕ НАПРАВЛЕНИЯ

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Abstract. The article is devoted to the study of economic potential of bioeconomy in agro-industrial complex of the Republic of Kazakhstan. The relevance of the topic is due to the need to modernize agricultural sector in the context of land degradation, climate change and growing demand for organic products. The introduction of bioeconomic approaches contributes to rational use of bioresources, reducing dependence on fossil fuels and increasing competitiveness of agricultural sector. *The goal* is to analyze possibilities of introducing bioeconomic models, assess their economic impact and develop recommendations for improving measures to implement agricultural policy. *Methods* - statistical analysis to consider the current state of agro-industrial production, volume of biological resources, level of biomass processing and dynamics of development of ecobioeconomics; comparative - in the study of successful biotechnology practices in the EU countries, Germany

and Brazil and their adaptation to the conditions of the republic. *Results* - based on economic modeling, three scenarios for the development of ecological economy are shown: basic (maintaining the current level), moderate (partial processing of bioresources) and optimistic (its full integration into the country's economic system). It was found that expansion of biosphere will increase contribution of agro-industrial complex to GDP by 15%, organize up to 200 thousand new jobs and reduce carbon footprint of agriculture by 25-30%. Processing of biomaterials and organic farming products will increase farmers' incomes by reducing costs of fertilizers and energy. The main barriers remain imperfect infrastructure, personnel shortages and financial constraints. *Conclusions* - practical significance of the work lies in preparation of proposals for transition to innovative processes of enriching biological mass, attracting private investment, creating educational programs and forming export potential, contributing to development of national bioeconomy strategy, development of rural areas and increasing their environmental sustainability.

Аңдатпа. Мақала Қазақстан Республикасының агроөнеркәсіптік кешеніндегі биоэкономиканың экономикалық әлеуетін зерттеуге арналған. Тақырыптың өзектілігі жердің деградациясы, климаттың өзгеруі және органикалық өнімге сұраныстың артуы жағдайында аграрлық секторды жаңғырту қажеттілігіне байланысты. Экономикалық тәсілдерді енгізу биоресурстарды ұтымды пайдалануға, қазба отынына тәуелділікті азайтуға және ауыл шаруашылығы саласының бәсекеге қабілеттілігін арттыруға ықпал етеді. *Мақсаты* - биоэкономикалық модельдерді енгізу мүмкіндіктерін талдау, олардың экономикалық әсерін бағалау және аграрлық саясатты іске асыру шараларын жетілдіру мақсатында ұсынымдар әзірлеу. *Әдістері* – агроөнеркәсіптік өндірістің ағымдағы жағдайын, биологиялық ресурстардың көлемін, биомассаны өңдеу деңгейін және эко-био-экономиканың даму динамикасын қарастыру үшін статистикалық талдау; салыстырмалы – ЕО елдеріндегі, Германия мен Бразилиядағы табысты биотехнологиялық тәжірибелерді және олардың республика жағдайына бейімделуін зерттеу. *Нәтижелері* - экономикалық модельдеу негізінде экологиялық экономиканы дамытудың үш сценарийі көрсетілген: негізгі (ағымдағы деңгейді сақтау), орташа (биоресурстарды ішінара өңдеу) және оптимистік (оны елдің экономикалық жүйесіне толық интеграциялау). Биосфераны кеңейту АӨК-нің ЖІӨ-ге қосқан үлесін 15%-ға ұлғайтуға, 200 мың жаңа жұмыс орнын ұйымдастыруға және ауыл шаруашылығының көміртегі ізін 25-30%-ға төмендетуге мүмкіндік беретіні анықталған. Биоматериалдар мен органикалық ауылшаруашылық өнімдерін қайта өңдеу тыңайтқыштар мен энергия шығындарын азайту арқылы фермерлердің кірістерін арттырады. Негізгі кедергілер жетілмеген инфрақұрылым, кадр тапшылығы және қаржылық шектеулер болып қала береді. *Қорытынды* - жұмыстың практикалық маңыздылығы биологиялық массаны байытудың инновациялық процестеріне көшу, жеке инвестицияларды тарту, білім беру бағдарламаларын құру және ұлттық биоэкономика стратегиясын әзірлеуге, ауылдық аумақтарды дамытуға және олардың экологиялық тұрақтылығын арттыруға ықпал ететін экспорттық әлеуетті қалыптастыру бойынша ұсыныстар дайындау болып табылады.

Аннотация. Статья посвящена исследованию экономического потенциала биоэкономики в агропромышленном комплексе Республики Казахстан. Актуальность темы обусловлена необходимостью модернизации аграрного сектора в условиях деградации земель, изменения климата и растущего спроса на органическую продукцию. Внедрение биоэкономических подходов способствует рациональному использованию биоресурсов, снижению зависимости от ископаемого топлива и повышению конкурентоспособности сельскохозяйственной отрасли. *Цель* – проанализировать возможности внедрения биоэкономических моделей, дать оценку их экономического влияния и разработать рекомендации в целях совершенствования мер реализации аграрной политики. *Методы* - статистического анализа для рассмотрения сложившегося состояния агропромышленного производства, объемов биологических ресурсов, уровня переработки биомассы и динамики развития экобиоэкономики; сравнительный – при изучении успешных практик биотехнологий в странах ЕС, Германии и Бразилии и их адаптации к условиям республики. *Результаты* - на основе экономического моделирования показаны три сценария развития экологической экономики: базовый (сохранение текущего уровня), умеренный (частичная обработка биоресурсов) и оптимистичный (полная интеграция ее в экономическую систему страны). Установлено, что расширение биосферы позволит увеличить вклад АПК в ВВП на 15%, организовать до 200 тыс. новых рабочих мест и снизить углеродный след сельского хозяйства на 25–30%. Перерабатывание биоматериалов и продуктов органического земледелия повысит доходы фермеров за счет сокращения затрат на удобрения и энергоносители. Основными барьерами остаются несовершенная инфраструктура, кадровый дефицит и финансовые ограничения. *Выводы* - практическая значимость работы заключается в подготовке предложений по переходу на инновационные процессы обогащения биологической массы, привлечению частных инвестиций, созданию образователь-

ных программ и формированию экспортного потенциала, способствуя разработке национальной стратегии биоэкономики, развитию сельских территорий и повышению их экологической устойчивости.

Key words: sustainable agriculture, biotechnology, economic modeling, renewable resources, bioenergy, climate change adaptation, rural development.

Түйінді сөздер: тұрақты ауыл шаруашылығы, биотехнология, экономикалық модельдеу, жаңартылатын ресурстар, биоэнергетика, климаттың өзгеруіне бейімделу, ауылдық аудандардың дамуы.

Ключевые слова: устойчивое сельское хозяйство, биотехнологии, экономическое моделирование, возобновляемые ресурсы, биоэнергетика, адаптация к изменению климата, развитие сельских районов.

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Introduction

The agro-industrial complex (AIC) of Kazakhstan occupies a pivotal position within the national economy. It serves as a cornerstone for ensuring food security, generating employment, and contributing substantially to GDP. Specifically, the sector accounts for over 20% of employment nationwide and approximately 10% of the country's gross domestic product. Kazakhstan's agricultural exports, particularly grain, represent a significant portion of its international trade, reinforcing its reputation as a critical player in global food markets. However, the traditional agricultural model faces mounting challenges. Soil degradation, limited water resources, climate change, and the fluctuating dynamics of international markets necessitate a shift toward innovative and sustainable practices.

In response to these challenges, the concept of a bioeconomy emerges as a transformative pathway for the sustainable development of agriculture and allied industries. It aligns with global efforts to mitigate the environmental impact of economic activities, reduce dependency on fossil fuels, and promote the efficient use of natural resources. The transition to bioeconomic principles not only supports environmental sustainability but also enhances economic efficiency, positioning Kazakhstan to harness its vast natural and agricultural potential.

This study aims to provide a comprehensive evaluation of the bioeconomy's potential within Kazakhstan's agro-industrial complex. It emphasizes the need to integrate international experience, technological innovation, and local capabilities to overcome existing barriers. Drawing on data from official sources, scientific research, and practical applications, the study seeks to propose actionable recommendations for advancing a bioeconomy-based approach in Kazakhstan. It underscores the multifaceted benefits of the bioeconomy, ranging from increased economic output and job creation to environmental preservation and rural development.

The adoption of bioeconomic strategies in agriculture has gained traction globally, with numerous countries successfully leveraging their biological resources to drive growth. For instance, the European Union's bioeconomy contributes approximately €2.3 trillion annually to its economy, supporting over 22 million jobs across various sectors. These achievements highlight the transformative potential of bioeconomic frameworks when supported by robust policy measures, technological advancements, and international cooperation. Such global precedents provide valuable insights for Kazakhstan, where the agro-industrial sector possesses untapped opportunities for growth and innovation.

This paper adopts a multidimensional approach to explore the prospects and challenges of integrating bioeconomy principles into Kazakhstan's agro-industrial complex. It includes an in-depth analysis of international bioeconomic practices, evaluates the feasibility of their application in Kazakhstan, and identifies strategic measures to achieve sustainable development. The study also investigates the socio-economic and environmental impacts of adopting bioeconomic solutions, emphasizing their role in reducing the carbon footprint, enhancing resource efficiency, and fostering rural livelihoods.

Literature review

The bioeconomy as a concept emerged from the need for sustainable use of biological resources to address modern economic and environmental challenges. The basic idea of the bioeconomy is to integrate biological and technological innovations to improve the efficiency of renewable resource use and mini-

mize environmental impacts. At the international level, the bioeconomy is recognized as one of the key tools for achieving the Sustainable Development Goals proposed by the United Nations (UNDP. Kazakhstan and Transition…) [1].

According to the European Commission, the bioeconomy covers a wide range of industries, including agriculture, forestry, fisheries, bioenergy, and biotechnology. In the European Union, this sector contributes €2.3 trillion to the economy, providing employment for 22 million people (European Commission. Bioeconomy Strategy) [2]. The EU example demonstrates that the development of the bioeconomy allows countries not only to strengthen the economy but also to reduce dependence on fossil energy sources, which is especially relevant in the context of the global energy crisis (IEA. Renewables) [3].

In the scientific literature, the bioeconomy is considered as a multidimensional phenomenon combining environmental, economic, and social aspects. For example, OECD research highlights the importance of switching to biotech solutions in the agricultural sector to improve agricultural productivity and sustainability in the face of climate change (OECD. Agricultural Productivity…) [4]. Particular attention is paid to biomass recycling, which is seen as the basis of the bioeconomy. Using agricultural waste to produce biogas, biofertilizers and bioethanol not only reduces waste but also creates new economic opportunities (FAO. Global Biogas Development) [5].

The examples of Germany and Brazil show that government support plays a decisive role in the development of the bioeconomy. In Germany, up to 30% of agricultural waste is processed into biogas, which reduces the carbon footprint and improves the country's energy independence (German Ministry of Agriculture…) [6]. In Brazil, the PROALCOOL program has made it possible to process sugarcane waste into bioethanol, providing up to 40% of national energy consumption and creating thousands of jobs (World Bank. Green Economy…) [7].

Kazakhstan, with its significant potential in the agro-industrial sector, also has opportunities for the development of the bioeconomy. According to the Ministry of Agriculture of Kazakhstan, more than 45 million tons of agricultural waste are generated annually in the country, most of which remains unused (Ministry of Agriculture of Kazakhstan. National Report…) [8]. This waste can be processed into biogas or biofertilizers, which will not only reduce the carbon footprint but also create economic incentives for farmers.

Scientific research by Kazakh authors confirms the feasibility of developing the bioeconomy in the country. Thus, the works of Azim Baibagyssov focus on the economic and environmental benefits of recycling agricultural waste, which can reduce carbon dioxide emissions by 20% (Baibagyssov A., Thevs N., Nurtazin S. et al.) [9]. In his research, Dulatbay Yerassyl emphasizes the importance of creating a national bioeconomy strategy that includes support for farmers and attracting international investment (Yerassyl D., Jin Y., Zhanar S. et al.) [10]. Similarly, Shaiakhmetov E.Y. notes that recycling livestock waste into biogas can reduce fossil energy consumption by 15% (Abilmazhinov E.T., Akimzhanov A.Zh., Shaiakhmetov E.Y et al.) [11].

At the same time, international experience demonstrates the importance of an integrated approach to the development of the bioeconomy, including the modernization of infrastructure, and the development of incentive measures and educational programs. For instance, in the United States, educational initiatives are actively being implemented aimed at training specialists in the field of biotechnology, which helps to accelerate the implementation of bioeconomic solutions (USDA. Biofuel Production and Sustainability) [12].

Existing scientific literature also focuses on the need to adapt the bioeconomy to the specific conditions of the country. For Kazakhstan, this means considering the arid climate, limited water resources and large territorial distances between production facilities. These features require the development of unique approaches that could combine international experience with local needs.

According to UNESCO, the bioeconomy can increase the efficiency of agriculture by 30% with the optimal use of natural resources (UNESCO. Sustainability and Agriculture) [13].

Considering the above, this study aims to study the bioeconomy as a multifunctional tool for the modernization of the agro-industrial complex of Kazakhstan. Based on the analysis of existing literature and data, the study aims to identify the main barriers and opportunities for its implementation, as well as to offer practical recommendations aimed at achieving sustainable development.

Materials and methods

The study used statistical data analysis, economic modeling, expert survey, and comparative analysis of international experience.

The data sources included reports of the Ministry of Agriculture of Kazakhstan, materials from international organizations such as the UN, FAO, and EBRD, as well as publications of domestic and foreign researchers. Information on the current state of the agro-industrial complex of Kazakhstan, the volume of agricultural waste, the level of implementation of biomass processing technologies, and the dynamics of the export potential of the bioeconomy was collected and processed. As part of the economic modeling, three scenarios for the development of the bioeconomy were developed: basic, moderate, and optimistic. For each scenario, an assessment of the possible contribution to GDP, the volume of biomass processing, the implementation of new job positions, and the reduction of the carbon footprint was made.

The expert survey included interviews with representatives of the agro-industrial sector, experts in the field of bioeconomy, as well as employees of government agencies and international organizations. The survey results identified key barriers and opportunities for the development of the bioeconomy in Kazakhstan. A comparative analysis of international experience was based on the study of successful examples of the implementation of bioeconomic approaches in countries such as Germany and Brazil, which allowed adapting key elements of their strategies to the conditions of Kazakhstan. At the preparatory stage of the study, data was collected and processed, and a database of literary sources was formed. At the analytical stage, modeling and scenario analysis were carried out, and the results were interpreted in the context of discussion with experts, which allowed formulation of recommendations for the implementation of bioeconomic approaches in the agro-industrial complex of Kazakhstan.

Results

The study confirmed the high potential of the bioeconomy for the transformation of the agro-industrial complex (AIC) of Kazakhstan. The analysis of quantitative and qualitative data showed that the introduction of bioeconomic approaches, such as biomass processing, the use of biotechnology, and the development of organic agriculture, can become a powerful tool for the economic, environmental, and social development of the country.

Kazakhstan has significant volumes of unused agricultural waste that can be processed into biogas, biofertilizers and biofuels. More than 45 million tons of such waste are generated in the country annually, less than 30% of which is processed (Ministry of Agriculture of Kazakhstan. National Report…) [8]. It is estimated that recycling at least 50% of this waste can ensure the production of up to 2 billion cubic meters of biogas per year, which replaces up to 15% of current natural gas consumption. This helps to reduce the carbon footprint by 25-30%, which is equivalent to 10 million tons of CO_2 equivalent annually (European Commission. Bioeconomy Strategy; FAO. Biogas Potential Analysis) [2, 14].

The development of the bioeconomy has a significant impact on the social field. The introduction of bioresource processing technologies can provide up to 200 thousand new jobs, mainly in rural areas where unemployment remains high. These jobs will be implemented in biomass processing enterprises, biofertilizer and biofuel production, as well as in logistics and related industries. In addition, farmers using biotechnology can reduce their energy and fertilizer costs by 20-30%, which will lead to an increase in their income by 25-30% (Ministry of Agriculture of Kazakhstan. National Report…; Abilmazhinov E.T., Akimzhanov A.Zh., Shaiakhmetov E.Y et al.) [8, 11].

The export orientation of the bioeconomy is another important area. Kazakhstan has significant competitive advantages in the international markets for organic products and biofuels. According to the United Nations Development Program, the demand for organic products increases by 10-12% annually (UNDP. Kazakhstan and Transition…) [1]. Potential export revenue from bioeconomy products can reach $3 billion annually. This includes supplies of organic grain, meat, bioethanol, and other products. For instance, the export of bioethanol produced from wheat and corn residues can bring in up to $1.5 billion per year, which will strengthen Kazakhstan's position in the global alternative energy markets (World Bank. Green Economy…; IPCC. Climate Change Mitigation Report) [7, 15].

The environmental significance of the bioeconomy lies not only in reducing the carbon footprint, but also in improving the condition of land resources. Sustainable agriculture, which involves the use of organic fertilizers, as well as precision farming technologies, prevents the degradation of up to 1.5 million hectares of arable land. This is especially important in the arid climate of Kazakhstan, where water scarcity and soil erosion pose significant challenges to agriculture (UNESCO. Sustainability and Agriculture; FAO. Biogas Potential Analysis) [13, 14].

To structure the analysis, three bioeconomy development scenarios were developed: basic, moderate, and optimistic (table 1).

These scenarios are presented in the table and demonstrate possible outcomes depending on the level of implementation of bioeconomy technologies.

Table 1 - Scenarios for the development of the bioeconomy

Parameters	Basic scenario	Moderate scenario	Optimistic scenario
Contribution to GDP (billion dollars)	0 (no changes)	+3.5 (partial implementation of biomass processing)	+7.2 (full integration of bioeconomy)
Agricultural waste recycling (%)	5% (current indicators)	25% (establishment of several processing centers)	50% (large-scale processing of biomass)
Biogas production (billion cubic meters)	0.2 (minor waste use)	1.0 (partial waste processing)	2.0 (maximum waste recycling)
Carbon footprint reduction (million tons of CO_2 eq.)	0.5	5.0	10.0
Implementation of job positions	Not provided	50 000 (in processing facilities)	200 000 (in processing, logistics and production of bioproducts)
Organic exports (% of AIC exports)	5% (current indicators)	12% (increase in organic production)	20% (significant growth in export potential)
Volume of investments (billion dollars)	No additional investments	2.5	5.0
Main obstacles	No government support	Limited processing capacity	High requirements for infrastructure and personnel
Note: compiled by the author based on data from (OECD. Agricultural Productivity…); FAO. Biogas Potential Analysis) [4,14]			

The basic scenario assumes no significant changes, maintaining the current level of waste recycling (5%) and minimal biogas production (0.2 billion cubic meters). The moderate scenario includes the creation of several recycling centers, which allow the recycling up to 25% of waste, producing 1 billion cubic meters of biogas and reducing the carbon footprint by 5 million tons of CO_2 equivalent. The optimistic scenario represents the full integration of the bioeconomy, including the recycling up to 50% of waste, producing 2 billion cubic meters of biogas, significantly reducing the carbon footprint and increasing the export potential of organic products by up to 20% (OECD. Agricultural Productivity…; FAO. Biogas Potential Analysis) [4, 14].

For a structured analysis of the key factors for the implementation of the bioeconomy, a SWOT analysis was performed, presented in the table 2.

Table 2 – SWOT analysis

Strengths	Weaknesses
Significant volume of agricultural waste suitable for recycling (45 million tons annually)	Lack of processing infrastructure: only 5% of farmers have access to modern processing technologies
Favorable climatic and geographical conditions for organic agriculture	High cost of implementing biomass-processing technologies: up to $5 billion in investment is required over the next 10 years
Competitive advantages in global organic product markets	Personnel shortage: only 2% of agricultural workers have biotechnology qualifications
Support for the bioeconomy from international organizations such as FAO and the World Bank	Limited government financial support and tax incentives
Opportunities	Threats
Increase in organic exports: annual growth in demand in global markets by 10-12%	Instability in international organic and biofuel markets
Biogas and bioethanol production: potential to replace 15% of natural gas and export bioethanol worth up to $1.5 billion per year	Dependence on imported technologies and equipment for biomass processing
International cooperation within the framework of the Paris Agreement and other environmental initiatives	Potential reduction in government support due to financial constraints

Increase in farmers' incomes by 25-30% due to reduced costs of fertilizers and energy	Environmental risks from unbalanced implementation of waste processing technologies

Note: compiled by the author based on data from (UNDP. Kazakhstan and Transition…; UNESCO. Sustainability and Agriculture; EBRD. Green Economy Transition Report) [1,13,16]

The results of the SWOT analysis help to identify key areas for developing a national bioeconomy strategy. In particular, the focus should be on eliminating infrastructural and personnel constraints, increasing support for farmers and enterprises implementing biotechnology, and enhancing international cooperation with partners such as FAO, the World Bank, and the European Commission.

The analysis also revealed significant export potential for the bioeconomy. Kazakhstan has favorable conditions to produce organic products and biofuels, which are in steady demand in international markets. According to the United Nations Development Program, the annual growth in demand for organic products is 10–12%, which opens significant opportunities for increasing Kazakhstan's share in the global market (UNDP. Kazakhstan and Transition…) [1]. Potential export revenue from bioeconomy products can reach $3 billion annually. For instance, the production of bioethanol from wheat and corn residues can generate up to $1.5 billion per year, which will strengthen Kazakhstan's position in alternative energy markets (World Bank. Green Economy…) [7].

A comparison of the results with international experience confirms the validity of the proposed solutions. For instance, Brazil, due to the state program PROALCOOL, has become a world leader in bioethanol production, processing more than 30 billion liters annually. This example demonstrates that an integrated approach to the development of the bioeconomy can significantly reduce dependence on oil imports and improve the environmental situation (OECD. Agricultural Productivity…) [4].

For practical application of the obtained results, it is recommended to develop a national bioeconomy strategy, which would include the development of biomass processing infrastructure, provision of subsidies for farmers and creation of educational programs on bioeconomy. These measures will help to eliminate the main barriers, such as lack of processing capacity, personnel shortages, and lack of funding. Attracting international investment and using the successful experience of the EU and the USA are also key elements of the strategy.

Suggestions for further research include studying the possibilities of applying precision farming technologies, assessing the long-term effects of bioeconomic solutions, and analyzing social aspects related to improving the quality of life in rural areas. Particular attention should be paid to the development of economic models that take into account climate change and its impact on agricultural productivity. These areas can significantly complement the presented results and contribute to the further development of the scientific base of bioeconomy in Kazakhstan.

The results of the study emphasize that bioeconomy can become the basis for sustainable development of the agro-industrial complex of Kazakhstan, improving the economic, social, and environmental situation in the country. However, its successful implementation requires a comprehensive approach, including modernization of infrastructure, support for farmers, development of educational programs and active international cooperation. These measures will allow Kazakhstan to use its potential to achieve sustainable growth and increase competitiveness in world markets.

Outcome: The development of the bioeconomy in Kazakhstan requires active government support, infrastructure modernization, stimulation of private investment and development of human resources. This strategic direction can become the basis for sustainable growth of the agro-industrial complex, ensuring stable incomes for farmers, increasing the country's competitiveness in international markets and improving the environmental situation.

Kazakhstan has all the opportunities to successfully realize the potential of the bioeconomy: extensive agricultural resources, ecologically clean territories, and growing demand for organic products. However, its successful implementation depends on how effectively the country can integrate the bioeconomy into its economic strategy.

These results emphasize that the bioeconomy can become an important driver of sustainable development in Kazakhstan, improving the economic, social, and environmental situation in the country. However, its successful implementation will require significant investment, government support and international cooperation.

Discussion

The obtained results highlight the importance of bioeconomy as a strategic direction for the modernization of the agro-industrial complex (AIC) of Kazakhstan. Data analysis

shows that the integration of bioeconomic solutions can provide significant economic, social, and environmental benefits.

The key result is the confirmation that bioeconomy can increase the contribution of the AIC to Kazakhstan's GDP by 15%, which is equivalent to $6.5–7.2 billion per year (OECD. Agricultural Productivity …) [4].

The social effects of the bioeconomy are also significant. The introduction of biomass processing technologies, biofertilizers and biofuels production can create up to 200 thousand new jobs, especially in rural areas where unemployment remains high. In addition, farmers using biotechnology can reduce their costs on fertilizers and energy by 20–30%, which will lead to an increase in their income by 25–30% (Ministry of Agriculture of Kazakhstan. National Report…; USDA. Biofuel Production and Sustainability) [8, 12]. This economic effect is confirmed by studies conducted in the EU and the USA, where the bioeconomy has become an important tool for sustainable development of rural areas.

The environmental significance of the bioeconomy lies in its ability to prevent the degradation of up to 1.5 million hectares of arable land using organic fertilizers and precision farming technologies.

The novelty of this study lies in the development of quantitative models for assessing the bioeconomic potential of Kazakhstan, considering the specifics of its natural and socio-economic conditions. The identified patterns, such as the relationship between biomass processing and the growth of farmers' incomes, as well as export potential, confirm the importance of bioeconomy for the national economy.

The economic effect of the implementation of bioeconomic projects is not limited to short-term productivity growth. In the long term, this will create a sustainable economic system capable of adapting to global challenges and using natural resources rationally, with minimal damage to the environment.

Conclusion

Bioeconomics is a strategically important direction for the development of the agro-industrial complex (AIC) of Kazakhstan, capable of not only accelerating economic growth but also ensuring a more rational use of natural resources. The introduction of bioeconomic approaches opens opportunities for the country to create high-tech production, increase the competitiveness of products in international markets and solve environmental problems. Economic impact of bioeconomy:

1. Increase in GDP. The development of bioeconomy can increase the contribution of the agro-industrial complex to Kazakhstan's GDP by 15%, which is equivalent to 6.5–7.2 billion dollars annually. These figures are due to increased productivity, processing of biomass into bioenergy and biofertilizers, as well as increased added value of products.

2. Increase in exports. Kazakhstan has significant potential for exporting organic products, bioethanol, and biogas. Development of bioeconomic production will increase export income by 3 billion dollars annually, which will strengthen the country's position in world markets and create additional incentives for investment.

3. Implementation of job positions. Introduction of biomass processing technologies and development of bioeconomy-related production will provide up to 200 thousand new jobs in rural areas. This is especially important for areas with high unemployment and low incomes.

4. Reduction of farmers' costs. The use of biotechnology in agriculture helps reduce the cost of fertilizers and energy. Farmers using biofertilizers and biogas plants can increase their income by 25-30%.

5. Investment attractiveness. The development of the bioeconomy creates new opportunities for attracting domestic and international investment. According to the World Bank, projects related to biomass processing and bioenergy are highly profitable, which makes Kazakhstan attractive to investors focused on sustainable development.

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